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CITATION:

Yoshii, Yutaka. Eigenvalues of Cartan matrices for group algebras of finite groups (Algebraic Combinatorics and related groups and algebras). 数理解析研究所講究録 2010, 1687: 152-156

ISSUE DATE:

2010-05

URL:

<http://hdl.handle.net/2433/141480>

RIGHT:

# Eigenvalues of Cartan matrices for group algebras of finite groups

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## 1 Introduction

Let  $G$  be a finite group,  $k$  an algebraically closed field of characteristic  $p > 0$ , and let  $B$  be a block of the group algebra  $kG$  with defect group  $D$ . Let  $C_B$  be the Cartan matrix of  $B$ , and let  $\rho(C_B)$  be the largest eigenvalue of  $C_B$  which is called *Frobenius-Perron eigenvalue*. Let  $R_B$  and  $E_B$  be the sets of all eigenvalues and all elementary divisors (with multiplicity) respectively. Let  $B_0(G)$  be the principal block of  $kG$ . Let  $O_{p'}(G)$  be the largest normal subgroup of  $G$  whose order is prime to  $p$ , and let  $O^{p'}(G)$  be the smallest normal subgroup of  $G$  whose index is prime to  $p$ .

The eigenvalues of Cartan matrices of finite groups have been studied by some people around T.Wada. The following conjecture is given in [4]:

**Conjecture 1.1** [4, Questions 1 and 2] *The following conditions are equivalent:*

- (a)  $\rho(C_B) \in \mathbb{Z}$ .
- (b)  $\rho(C_B) = |D|$ .
- (c)  $R_B = E_B$ .

It is clear that (c)  $\Rightarrow$  (b)  $\Rightarrow$  (a). This conjecture is known to be true in the following cases:

- $D$  a cyclic group (see [3, Corollary 4.8] and [4, Proposition 3]),
- $D$  isomorphic to a dihedral, a semidihedral, or a generalized quaternion group (see [4, Proposition 4]),
- The principal block with  $D$  abelian when  $p = 2$  (see [7, Theorem]),

- The principal block with  $D$  an elementary abelian group of order 9 (see [9, Theorem C]).

Moreover, in these cases, the conditions in Conjecture 1.1 are equivalent to the condition

(d)  $B$  is Morita equivalent to the Brauer correspondent  $b$  in  $N_G(D)$ .

It is known that (d) implies (c) in general (see [4, Proposition 2]), but the converse is not always true (see [4, Example]). Nevertheless, if  $D$  is abelian, then all of these conditions are expected to be equivalent:

**Conjecture 1.2** *If  $D$  is abelian, then the above conditions (a)-(d) are equivalent.*

## 2 Results

We assert that Conjecture 1.2 is true for the principal block of an arbitrary group with an abelian Sylow 3-subgroup, which is a generalization of Wada's result [9, Theorem C]. This is a joint work with Shigeo Koshitani.

**Theorem 2.1** (see [6, Theorem 1.4]) *Let  $G$  be a finite group with an abelian Sylow 3-subgroup  $D$ , and let  $B$  be the principal 3-block of  $kG$ . Then the following conditions are equivalent.*

- (a)  $\rho(C_B) \in \mathbb{Z}$ .
- (b)  $\rho(C_B) = |D|$ .
- (c)  $R_B = E_B$ .
- (d)  $B$  is Morita equivalent (even stronger Puig equivalent) to the Brauer correspondent  $b$  in  $N_G(D)$ .
- (e) Set  $\tilde{G} = O_{3'}(G/O^{3'}(G))$ . Then

$$\tilde{G} \cong S \times G_1 \times \cdots \times G_r$$

*for some positive integer  $r$ , where  $S$  is an abelian 3-group and each  $G_i$  is one of the following nonabelian simple groups:*

- (1) nonabelian simple groups with cyclic Sylow 3-groups,
- (2)  $\text{PSU}_3(q^2)$  with  $3|q+1$  and  $3^2 \nmid q+1$ ,
- (3)  $\text{PSp}_4(q)$  with  $3|q-1$ ,

- (4)  $\text{PSL}_5(q)$  with  $3|q+1$  and  $3^2 \nmid q+1$ ,
- (5)  $\text{PSU}_4(q^2)$  with  $3|q-1$ ,
- (6)  $\text{PSU}_5(q^2)$  with  $3|q-1$ .

The proof is essentially similar to that of [9, Theorem C] for  $D \cong C_3 \times C_3$  or [7, Theorem] for  $p = 2$ . But in our case, some additional tools are needed to prove (a)  $\Rightarrow$  (e). The following lemma is useful to reduce the condition (a) to  $B_0(\tilde{G})$ .

**Lemma 2.1** (see [8, Theorem 1.1]) *Let  $G$  be a finite group and let  $H$  be a normal subgroup of  $G$  whose index is not divisible by  $p$ . Let  $b$  be a  $(p-)$ block of  $H$  and let  $B$  be a block of  $G$  covering  $b$ . Then  $\rho(C_B) = \rho(C_b)$ .*

Moreover, since  $\rho(C_{B_0(\tilde{G})}) = |S| \times \rho(C_{B_0(G_1)}) \times \cdots \times \rho(C_{B_0(G_r)})$ , the following lemma enables us to reduce the condition (a) for  $B_0(\tilde{G})$  to each  $B_0(G_i)$ .

**Lemma 2.2** (see [6, Lemma 2.3]) *Let*

$$f(x) = x^m + a_{m-1}x^{m-1} + \cdots + a_1x + a_0,$$

$$g(x) = x^n + b_{n-1}x^{n-1} + \cdots + b_1x + b_0$$

*be two  $\mathbb{Z}$ -polynomials with  $m, n \geq 1$ . Suppose that  $\alpha_1, \dots, \alpha_m$  and  $\beta_1, \dots, \beta_n$  be the roots of  $f(x)$  and  $g(x)$ . Moreover, we assume that all roots of  $f(x)$  and  $g(x)$  are real and*

$$\alpha_1 > \alpha_2 \geq \cdots \geq \alpha_m > 0 \text{ and } \beta_1 > \beta_2 \geq \cdots \geq \beta_n > 0$$

*(but if  $m = 1$  (resp.  $n = 1$ ), this means  $\alpha_1 > 0$  (resp.  $\beta_1 > 0$ )). Then, if  $\alpha_1\beta_1 \in \mathbb{Z}$ , then  $\alpha_1 \in \mathbb{Z}$  and  $\beta_1 \in \mathbb{Z}$ .*

In general, it is known that for a finite group  $G$  with nontrivial abelian Sylow 3-subgroup such that  $O_{3'}(G) = 1$  and  $O^{3'}(G) = G$ , the form of  $G$  is

$$G = S \times G_1 \times \cdots \times G_r,$$

where  $S$  is an abelian 3-group and each  $G_i$  is one of the nonabelian simple groups in a list (see [5, Proposition 1.1]). So it suffices to check the condition (a) for the groups in the list. But for almost all of the groups the condition (a) is checked in [9], so we only have to check for the principal blocks of the following groups:

- the O’Nan simple group  $O’N$ ,
- $\mathrm{PSL}_4(q)$  with  $3|q+1$ ,
- $\mathrm{PSL}_5(q)$  with  $3^2|q+1$ ,
- $\mathrm{PSp}_4(q)$  with  $3|q+1$ ,
- $\mathrm{PSL}_2(q)$  with  $q=3^n$ ,  $n=3, 4, 5, \dots$ .

It is easy to check it for the principal block of  $O’N$ . Indeed, we can check directly that the condition (a) does not hold for the block. So we only have to check it for the other groups. In fact, by the result of Alperin [1] and Dade [2] we can reduce to  $\mathrm{GL}_4(q)$ ,  $\mathrm{GL}_5(q)$ ,  $\mathrm{Sp}_4(q)$ , and  $\mathrm{SL}_2(q)$  respectively. Now we have the following result:

**Theorem 2.2** *Let  $B_0$  be the principal block of  $kG$ , and let  $D$  be a Sylow  $p$ -subgroup of  $G$ .*

- (1) *If  $G = \mathrm{GL}_4(q)$ ,  $p$  is odd and  $p|q+1$ , then  $\rho(C_{B_0}) \notin \mathbb{Z}$ .*
- (2) *If  $G = \mathrm{GL}_5(q)$ ,  $p$  is odd and  $p|q+1$ , then  $\rho(C_{B_0}) \notin \mathbb{Z}$  except when  $p=3$  and  $3^2 \nmid q+1$ .*
- (3) *If  $G = \mathrm{Sp}_4(q)$ ,  $p$  is odd and  $p|q+1$ , then  $\rho(C_{B_0}) \notin \mathbb{Z}$ .*
- (4) *If  $G = \mathrm{SL}_2(q)$ , with  $q=3^n$  with  $n \geq 2$ , then  $\rho(C_{B_0}) \notin \mathbb{Z}$ .*

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